Indian J. Phys. **74B** (2), 133–138 (2000)

I J P B
- an international journal

The effect of solar flare index on seasonal variation of 6300 Å nightglow emissions at Calcutta and some statistical inferences

R Chattopadhyay[1], S K Midya[2*] and U K De[3]
[1]Haripal G. D. Institution, Khamarchandi-712 405, Hooghly, West Bengal, India
[2]Department of Physics, Serampore College, Serampore-712 201, Hooghly, West Bengal, India
[3]Atmospheric Science Division, Physics Department, Jadavpur University, Jadavpur, Calcutta-700 032, West Bengal, India

Received 15 March 1999, accepted 10 November 1999

Abstract : Seasonal covariation of oxygen red line [OI] 6300 Å nightglow intensity at Calcutta and solar flare index for non-peak phase of 21st solar cycle has been reported and analysed in comparison with the same at Cachoeira paulista [1] for peak phase of the same 21st solar cycle. Two different modes of variations namely the local and the global, are found to exist in both [OI] 6300 Å line intensity and solar flare index. Probable causes of such type of variation have been discussed on all possible factors that have been investigated out by a large number of workers Solar surface-differential rotation of higher order is the most prime suspect amongst all possible means of solar control of terrestrial ionospheric emission activities. Gravity waves, magnetic effect *etc.* have been found to be very closely associated with the changes in ionospheric electron density and thereby on the various ionospheric emission processes.

Keywords : Night-airglow, solar flare index, ionospheric activities.

PACS Nos. : 94.10.Rk, 94.20.Ji, 93.30.Db

1. Introduction

[OI] 6300 Å nightglow emission line generally originates from the forbidden transition $O(^1D) \rightarrow O(^3P_2)$ and $O(^1D)$ is usually produced in different ways such as Schumann-Runge dissociation, photodetachment, ionospheric recombination *etc.*, amongst which the ionospheric recombination plays the major role in producing oxygen red line at night [2] :

$$O_2^+ + e \rightarrow O^*(^1D, ^1S) + O.$$

O_2^+ can again be produced in different ways such as charge exchange photo-dissociation *etc.* with O_2. Hence, the intensity of [OI] 6300 Å line depends primarily on the concentration of O_2 and ionospheric electron densities. Again, concentration of O_2 and Ionospheric Electron Content (IEC) have peak values within the altitude region of peak F_2-layer of ionosphere for which two main ionospheric terms have been made significantly indicative and they are the critical frequency of F_2-layer ($f_0\,F_2$) and virtual height of F_2-layer ($h'\,F$). A semiempirical relation connecting directly $f_0\,F_2$ and $h'F$ with [OI] 6300 Å nightglow intensity, which was first established by Barbier [3], has been found to hold good in general.

The effect of solar parameters on different airglow emission lines has been investigated by different investigators [1,4,5]. It has been reported that intensity of 5577 Å and 5893 Å lines vary periodically with different solar parameters [5–7]. In all these studies variation in intensities of various airglow lines have been correlated with variations in relative sunspot number (RSSN), solar flare number (SOLFN) *etc.* But according to Sawyer [8], solar flare index (I_f) is the proper representative of total energy flux output of flare events and therefore is more significant than the other solar parameters, in general. We have studied the effect of solar flare index on the seasonal variation of oxygen red (6300 Å) line and present the results in this paper along with statistical inferences.

2. Experimental arrangement and observations

Dunn-Manring type photometer was used to observe [OI] 6300 Å line intensity, the detail arrangement of which can

*Centre for Space Physics, H A 326/7, Salt Lake, Calcutta-700 097, West Bengal, India

from night sky was allowed to be incident after passing through a converging lens and and then through the band-pass filter having peak at 6300 Å a narrow band-width on the cathode of the photoelectric detector (Figure 1).

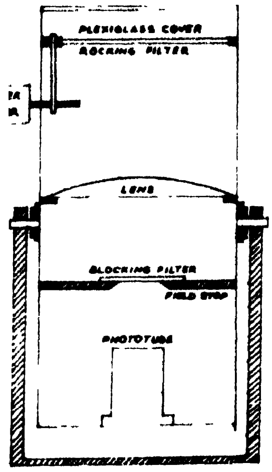

Figure 1. Experimental arrangement (diagramatically presented).

Integrated over a small yet appreciable period of time, the flux yielded a measurable photocurrent. The observations were taken at R. K. Mission Residential College, Narendrapur (Lat. 22°35' N, Long. 80°21'E) very close to Calcutta. Photocurrent was found to very perfectly linearly with the [OI] 6300 Å line intensity and was considered the only representative of [OI] 6300 Å line intensity ([OI] 6300 Å LI). Half-hourly intensities for the dark hours of nights are averaged. The monthly mean is obtained from the average intensities having more than eight hours' observation in a night. Here, it is relevant to mention the fact that nightglow data of [OI] 6300 Å during two or three months of summer and monsoon have been obtained by means of interpolated data for a few days with clear sky during that period. The above observations were taken during the period 1984–1985–1986, the non-peak phase of 21st solar cycle. Observation of Sahai *et al* [1] on [OI] 6300 Å line intensity variation at Cachoeira Paulista (Lat. 22°7'S, Long. 45°W) taken during the period 1978–1979–1980, the peak phase of 21st solar cycle has been considered for a comparison.

3. Data analysis, results and discussion

In our previous work [10], the effects of 10.7 cm solar flux, solar flare number and relative sunspot number on the seasonal variation of nightglow 6300 Å oxygen red line intensity have been studied and with the help of simple statistical method, the following interesting results have been found out :

1) 12-monthly running average of nightglow [OI] 6300 Å oxygen red line intensity has been found to have a very strong correlation with 12-monthly running average of each of the above mentioned three solar parameters;
2) The variable parts of these three quantities, which means the original value minus running average, shows periodic seasonal variation;
3) The variable part of [OI] 6300 Å line intensity has been found to vary quasi-periodically with the variable parts of each of the three solar parameters mentioned above.

In our present analysis, similar study has been made on the seasonal covariation of running averages and variable parts of [OI] 6300 Å nightglow intensity and solar flare index (I_f) separately. Solar flare index has been calculated [8] using the following equation,

$$I_f = \frac{0.76 \sum A_d}{T^*}$$

The values of flare areas in millionth of solar disk (A_d) and the effective observing time in minutes (T^*) have been obtained from the Solar Geophysical Data (Comprehensive and prompt report) published by NOAA, Dept. of Commerce, USA. Due to nonavailability of data for some months during three or four years, interpolated values from regression relation between I_f and relative sunspot number, given in Midya *et al* [7] have been used here. Monthly mean values of I_f for the ascending and descending phases of 21st solar cycle have been considered. Monthly mean values of [OI] 6300 Å line intensity ([OI] 6300 Å LI) for descending phase of 21st solar cycle have been taken from previous paper [10] and for peak phase of 21st solar cycle has been taken from Sahai *et al*'s observations [1]. The scatter diagram for [OI] 6300 Å LI with I_f for both peak and non-peak phases of 21st solar cycle is given in Figure 2. It is in general, found that the [OI] 6300 Å LI oscillates with the corresponding I_f values. Kazakov [11] too obtained such oscillation of airglow intensity with increase of solar activity. It is observed therefrom that the average periodic length of variation in terms of I_f is 4.3 in non-peak and 14.8 in peak phase which means that the rate of influences of I_f on the variation of [OI] 6300 Å LI is greater in non-peak phase than in the peak phase. Similar results were obtained by the authors for the variation in [OI] 6300 Å LI with other solar parameters [10].

It is also observed that if we take the 12-monthly running averages of [OI] 6300 Å LI and I_f, the two running averages bear a linear relationship between themselves. The peak phase data show a strong correlation with correlation coefficient equals to 0.94 and standard error equals to 0.02 while the non-peak phase data show relatively poor correlation with correlation coefficient equals to 0.32 and standard error equals to 0.26 (Table 1). It is therefore, inferred that there exists a correlation between the solar flare index and [OI] 6300 Å LI which is best manifested in their coefficient equals to 0.94 and standard error equals to 0.02 while the non-peak phase data show relatively poor correlation with correlation coefficient equals to 0.32 and standard error equals to 0.26 (Table 1). It is therefore, inferred that there exists a correlation between the solar flare

Table 1. Correlation coefficients for the covariation of running averages respectively of [OI] 6300 Å line intensity and I_f (21st solar cycle).

	Non-peak phase	Peak phase
Corr. coeff.	0.32	0.94
S.E	0.26	0.02

index and [OI] 6300 Å LI which is best manifested in their corresponding running average values. The correlation is very strong in peak phase of a solar cycle while it is relatively weaker in non-peak phase. Especially in the non-peak phase, we see a poor correlation between the two which may be accounted for mainly by the two following reasons; one is that the avaiable data is very small in length and therefore produces an appreciable error in the calculation of correlation coefficient. Thus, the value of correlation coefficient as obtained here for the non-peak phase, can not be accepted with extreme level of confidence. The other reason is that there is a general trend of low influence of the steady or global part of all kinds of solar activity on the ionospheric nightglow emission in non-peak phase of a solar cycle and this view has also been portrayd in previous paper [12]. Beside these, there are several types of anomalies in solar influences on terrestrial ionospheric activities which are discussed later in this section.

Another interesting feature shown in Figure 3, is that the variable part of solar flare index and [OI] 6300 Å nightglow intensity (VPI_f and VP [OI] 6300 Å LI respectively) which are the original values minus the running average value for a particular month of a year, show periodic variation between themselves and similar type of variation has also been observed for the original values of the corresponding parameters and mentioned earlier in this section. But the variation of the variable part of both the covarying parameters mentioned above has much greater significance than the variation of their original values because each of the VP I_f and VP [OI] 6300 Å LI shows separately a month-wise average periodicity equals to 5 to 6 months which fits exactly with the short term periodicity in solar disk [13,14]. The original values show some average periodicity much different from that. From Table 2, it is observed that the periodicity of variation of

Table 2. Average periodicity of variation of variable parts of [OI] 6300 Å line intensity and I_f in terms of months

	Non-peak phase		Peak phase	
	VP OI 6300 Å LI	VP I_f	VP OI 6300 Å LI	VP I_f
Lower loop	6	2.83	4.67	5 67
Lower loop	5	2 67	5 86	6.50

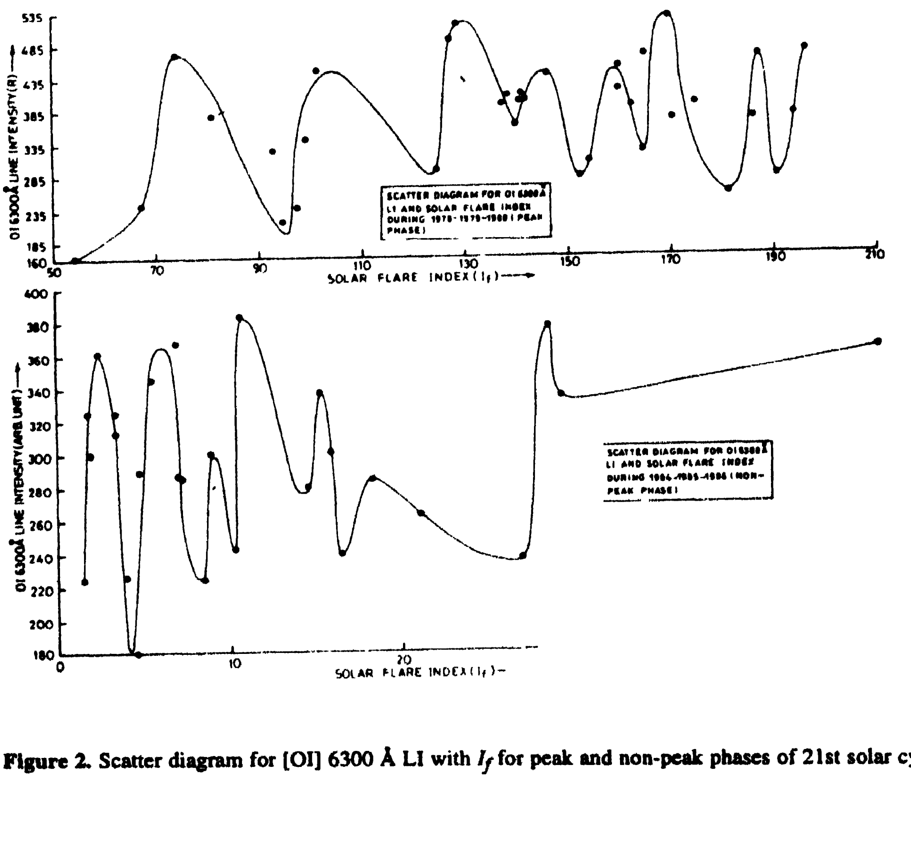

Figure 2. Scatter diagram for [OI] 6300 Å LI with I_f for peak and non-peak phases of 21st solar cycle.

the VP I_f in non-peak phase only differs from the above-mentioned periodicity. Periodicity of same range *i.e.* 5 to 6 months on an average, has also been reported by us in our previous paper [12] and also by many others [13–15] especially for 20th and 21st solar cycles. Bai and Sturrock [13] and Carbonell and Ballester [14] have shown that there

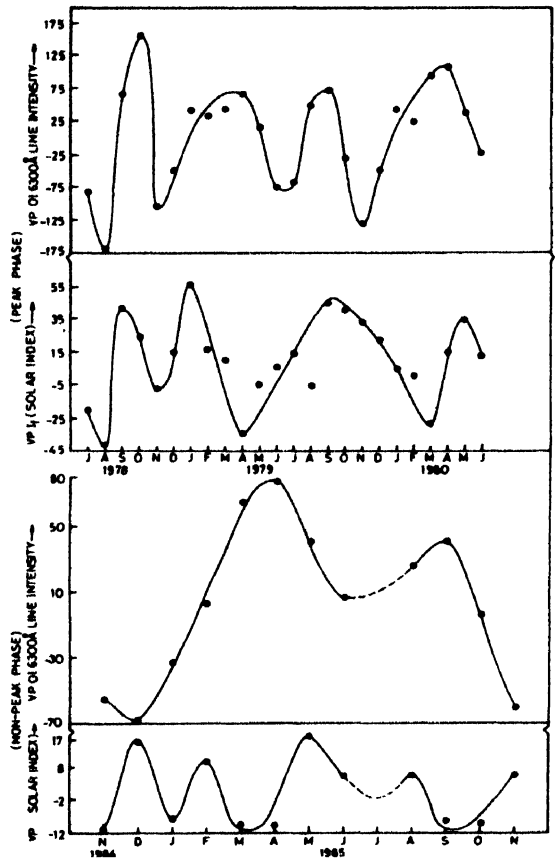

Figure 3. Month-wise plot of VP [OI] 6300 Å LI and VP I_f for peak and non-peak phase of 21st solar cycle.

exists an average short term periodicity of 5 to 6 months in various forms of solar activity such as H-flares, X-ray, γ-ray burst, high energy electrons in solar disk. Özgüc and Atäc [15] have reported that solar flare index shows an average periodicity of the same range especially for 21st solar cycle. Along with others, Javaraiah and Gokhale [16] have attributed such short term periodicity to the solar differential rotation of higher order. Figure 4 shows the scatter diagram between the VP I_f and VP [OI] 6300 Å oxygen red line intensity for both peak and non-peak phases of 21st solar cycle whenceforth it can be noticed that the average periodicity of variation of VP [OI] 6300 Å LI in terms of VP I_f is also greater in peak phase than in non-peak phase confirming again the proposition that the rate of influence of solar activity on the variation of [OI] 6300 Å LI is greater in non-peak phase than in peak phase. This fact is also consistent with the result that the average period in months, of variation of VP I_f in non-peak phase is less than that in peak phase and in calculating I_f values, one has to consider time factor as the denominator of the term. In explaining all these occurrences, one has to keep in mind that the mean periodicities of differential rotation in the sun

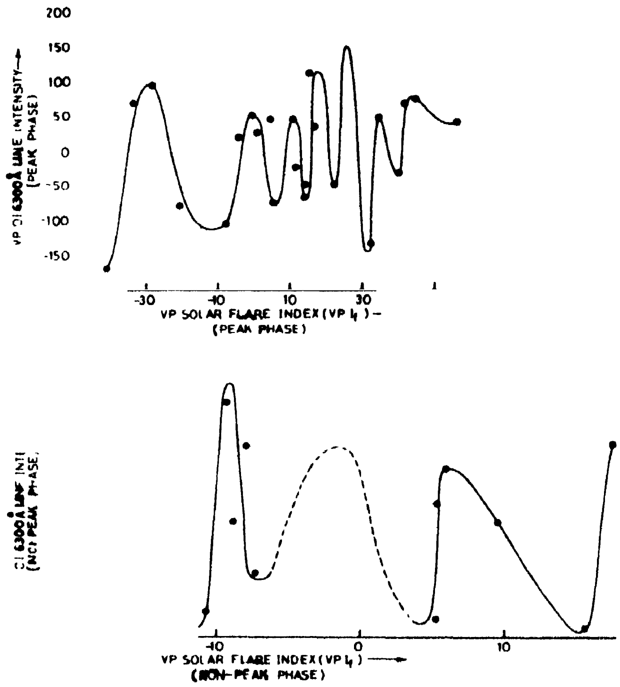

Figure 4. Scatter diagram for VP [OI] 6300 Å LI variation corresponding VP I_f for both peak and non-peak phases of 21st solar cycle.

must not be confused and correlated with the time factor in the calculation of I_f mentioned above. That is completely a different thing. Similar results have been reported by the authors in their previous paper [12] regarding the covariation of VP [OI] 6300 Å LI with the variable parts of different other solar parameters.

Figure 5 shows the regression line for the covariation of running average values of [OI] 6300 Å red line nightglow intensity and I_f for peak phase of 21st solar cycle. The equation is given below :

$$I_{6300\,\text{Å}}\ \text{(arb. unit)} = 1.36\, I_f + 198.49.$$

For the non-peak phase, the correlation between the running averages of [OI] 6300 Å LI and I_f has been found to be relatively poor and therefore, the regression relation has not been given so much importance.

Actually, running average is usually performed to remove local seasonal variations [1,2]. Hence, running average of [OI] 6300 Å and similarly, running average of solar parameters removes the solar surface-local seasonal variations in them. This study reveals an important fact that

that of I_f in peak phase although it is not exactly the same in non-peak phase as obtained here. This partial inconsistency between the peak and non-peak phase observations considered in this paper may be due to one or all of the following causes. As per the report of Bhuyan [17] there exists a longitudinal assymetry in the time of peak occurrences in $N_m F_2$ between Asian and South American low latitude sector. Our observing station and Sahai *et al*'s observing station are both low latitude stations

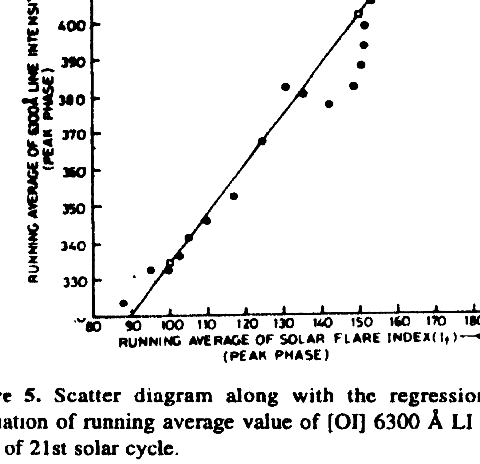

Figure 5. Scatter diagram along with the regression line for the covariation of running average value of [OI] 6300 Å LI and I_f for peak phase of 21st solar cycle.

but longitudinally they are far apart from each other and are on two different hemispheres. According to Sojka and Schunk [18], the solar cycle dependence is extremely systematic over the high latitude ionosphere. In the dark ionosphere, where direct photoionisation is no longer present, the solar cycle dependence is present due to the transport of sunlit day-side plasma into the dark regions of the polar ionosphere. This is further influenced by the neutral atmosphere that is globally sensitive to the solar cycle. Sojka and Schunk [18] also mention that seasonal modulation can also be found in $h_m F_2$ in which the night sector displays the strongest modulation. In the late evening and morning sectors, the neutral wind blows toward the equator and cause an upward induced plasma drift. The seasonal variation is generally much pronounced in northern hemisphere than in southern hemisphere. Again Sharma *et al* [19] have found that diurnal anisotropy in phase and amplitude for 21st solar cycle decreased in peak phase and increased in non-peak phase along with the reversibility of solar polar magnetic field.

Khachikjan *et al* [20] shows that longitudinal variation in $h_m F_2$ is produced mainly by the existence of longitudinal variation of the vertical plasma drift caused by the interaction of zonally averaged thermospheric wind with the corresponding longitudinal variation of geomagnetic field parameter. Fagundes *et al* [21] observed that thermospheri temperatures which were obtained from the Doppler broadening of the [OI] 6300 Å emission was found to oscillate which might have been partially caused by geomagnetic storm.

Mukherjee and Carlo [22] finds airglow 6300 Å line intensity enhancement during the nights, are generally associated with the TEC enhancement. Kolomiitsev *et al* [23] observes that temporal variation of the electron density in the F-region depends mainly on the initial profile parameters such as ionizing solar radiation flux, ion-formation rate, diffusion and geomagnetic activity. TIEGCM (Thermospheric ionospheric electrodynamic general circulation model) simulation by Fesen [24] suggests that the peak electron density in the F-layer is dependent on the relative contributions from perturbations due to auroral sources and the vertically propagating tides from the lower atmosphere. Since both these sources are quite variable, the perturbations induced by these sources are also variable. Adler *et al* [25] have shown that ionospheric electron density anomaly (N_{max} Å) and hence N_{max} (Maximum electron density) depends on decadal parameter and solar cycle length. Again N_{max} is the key parameter which controls the $f_0 F_2$ and thereby affecting the [OI] 6300 Å line intensity. Natural generation of small scale irregularities in F-region is, as per Kagan *et al's* view [26] sometimes caused by diagnostic stimulated electromagnetic emission—caused thermomagnetic instability. Jain *et al* [27], in their observations during the ascending phase of 21st solar cycle at Lunping (25°N, 121°.17'E), the latitude of which is very close to that of our station Narendrapur, found that peak amplitude, duration and time of peak for both the parameter scintillation index (SI) and ionospheric electron content (IEC) are highly correlated. The seasonal variation of both of hem showed periodic variation.

Generally, any oscillatory variation does occur between the variables of a sysem where generation of some variables is opposed by its rate of production. As, O ^1D in the F-region is similarly caused and favoured by solar energy flux and a subsequent cooling effect does occur [28] in that region due to [OI] 6300 Å line emission the usual life time of this radiation *i.e.* 3.1 hour, may be prolonged and hence averaged over a month, this may well yield a phase lag with corresponding solar parameter and thus an oscillatory scatter diagram between the airglow intensity mean and the mean values of solar parameters can be realistic. Muller *et al* [29] observed that the local ionospheric phenomena like wind speed, various types of atmospheric gravity waves, vertical plasma drift, geomagnetic activity *etc.* have been found to show periodic variations which have mean periodicities ranging from a few hours to some 10 or 20 days. It is well known that almost all the above-mentioned atmospheric activities are predominantly caused and controlled by solar thermal input to our atmosphere. Periodicities in the variations of ionospheric emission much larger than that of the above parameters of our atmosphere, are therefore to be primarily accounted for by the corresponding solar parameter variations. The above-mentioned atmospheric speed, various types of atmospheric gravity waves, vertical plasma drift, geomagnetic activity *etc*. have been found to show periodic variations which have mean periodicities ranging from a few hours to some 10 or 20 days. It is well known that almost all the above-mentioned atmospheric activities are predominantly caused and controlled by solar thermal input to our atmosphere. Periodicities in the variations of ionospheric emission much larger than that of the above parameters of our atmosphere, are therefore to be primarily accounted for by the corresponding solar parameter variations. The above-mentioned atmospheric phenomena may produce influence on the ionospheric emission activities only temporally and locally and not much secularly. The covariation, if any, between the ionospheric emission activities and all those above-mentioned atmospheric activities may on one hand, be due to the local coupling of activities and on the other hand, be due to the coherence of the causes of such variations from the single solar disk.

4. Conclusion

From the preceding section, the following conclusions can be drawn :

(i) The solar flare index like other solar parameters, have got different modes of variations, one the locally or internally stimulated and the other the globally or extrasolarly caused. The immediate local cause may be primarily the differential rotation in the sun while the extrasolar cause may be any kind of intragalactic interaction of sun with other objects.

(ii) Terrestrial ionospheric emission activities such as [OI] 6300 Å line intensity variation along with corresponding ionospheric parameters too may be thought of comprising two distinct modes of variation; the locally caused say, through vertical plasma drift, gravity waves, geomagnetic activities *etc*. while the other is the direct solar control of different ionospheric features.

(iii) The particular component of variation of [OI] 6300 Å line intensity which is directly solar controlled, bears a very straightforward linear relationship with corresponding solar flare index value although in non-peak phase, a little deviation is found and that deviation may or may not be only apparent. For specific arguments on this matter, more observations are needed.

(iv) The rate of influence of I_f on [OI] 6300 Å nightglow-line-intensity in general, increases and decreases respectively with decrease and increase of solar activity and therefore, the role of differential rotation in the sun on the local variation of I_f discussed so far in this paper, may be considered to be the most important.

Acknowledgments

The authors wish to offer their grateful thanks to the Librarian of the Department of Theoretical Physics, IACS, Jadavpur for providing one of the authors (RC) with library facilities and to Prof. S N Ghosh, Trustee, IACS, Jadavpur for his kind help in many respects.

References

[1] Y Sahai, H Takahashi, J A Bittencourt, J H A Sobral and N R Teixeira *J. Atmos. Terr. Phys.* **50** 2 135 (1988)

[2] R L Carovillano and J M Forbes *Eds. Solar Terrestrial Physics* (Dordrocht : D. Reidel) (1983)

[3] E H Carman and B P Kilfoyle *J. Geophys. Res.* **68** 19, 5605 (1963)

[4] Y Sahai, D H Giers, L L Cogger, P R Fagunder and G P Garbe *J Atmos. Terr. Phys.* **58** 16 1927 (1996)

[5] S K Midya, G Tarafdar and T K Das *Earth, Moon and Planets* **75** 177 (1996)

[6] S K Midya, G Tarafdar and T K Das *Earth, Moon and Planets* **63** 199 (1993)

[7] S K Midya, G Tarafdar and T K Das *Earth, Moon and Planets* **76** 135 (1998)

[8] C B Sawyer *J. Geophys. Res.* **72** 385 (1967)

[9] S N Ghosh and S K Midya *Indian J. Phys.* **69B** 413 (1986)

[10] S K Midya, R Chattopadhyay and C M Pal *Earth, Moon and Planets* **73** 93 (1997–1999)

[11] K Kazakov *C. R. Acad. Bulg. Sci.* (Bulgaria) **29** 991 (1976)

[12] R Chattoapadhyay, S K Midya and U K De (Communicated)

[13] T Bai and P A Sturrock *Nature* **350** 141 (1991)

[14] M Carbonell and J L Ballester *Astron. Astrophys.* **255** 350 (1992)

[15] A Ozguc and T Atac *Solar Phys* **123** 357 (1989)

[16] J Javaraiah and M H Gokhale *Solar Phys* **158** 173 (1995)

[17] P K Bhuyan *Indian J. Phys.* **68B** 231 (1994)

[18] J J Sojka and R W Schunk *J. Atmos. Sol. Terr. Phys.* **592** 207 (1997)

[19] N K Sharma, R D Singh and R S Yadav *Indian J. Phys.* **70B** 271 (1996)

[20] G Ja Khachikjan, A I Pogoreltsev and Ja V Drobjeva *J. Atmos Sol. Terr. Phys.* **59** 12 1391 (1997)

[21] P R Fagundes, Y Sahai, H Takahashi, D Gobbi and J A Bittencourt *J. Atmos. Terr. Phys.* **58** 16 1963 (1996)

[22] G K Mukherjee and L Carlo *J. Geomag. Geoelectr.* **46** 1029 (1994)

[23] O P Kolomittsev, B M Reddy and V A Surotkin *J. Atmos. Sol Terr. Phys.* **59** 11 1287 (1997)

[24] C G Fesen *J. Atmos. Sol. Terr. Phys.* **59** 1521 (1997)

[25] N O de Adler, A G Elias and J R Manzano *J. Atmos. Sol. Terr Phys.* **59** 2 159 (1997)

[26] L M Kagan and V L Frolov *J. Atmos. Terr. Phys.* **58** 13 1465 (1996)

[27] S Jain, S D Mishra, S K Vijay and A K Gwal *Indian J. Phys.* **72B** 1 (1998)

[28] J W Chamberlain *Theory of Planetary Atmosphere : An Introduction to Their Physics and Chemistry* (New York : Academic) (1978)

[29] K M Muller, U L Vike Langematz and Steven Pawson *J. Atmos. Sci.* **54** 2749 (1997)